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Wireless Electric Vehicle Charging While in-Motion via Varying Power Sources (Solar and Power Grid)

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ABSTRACT

The electric vehicles (EVs) charging by use of slow and fast chargers with plugin charging and pantograph has been adopted at many location across the United States. The EVs are inherently capable of being integrated with some smart operations with information technology in autonomous features. Given batteries in smart phones are capable of being charged either by cord or wirelessly, the EVs have similar charging capabilities. However, a concept of wirelessly charging the EV battery while in-motion is realistic and have a great potential in improving the travel experience for the customers. Some pilot projects around the United States have a proven success but at a low vehicle speed. This paper is focused on presenting a scheme for charging while in-motion for the EV batteries while in major highways where there is least interference of pedestrian conflicts. The application of such technology requires huge investment by the transportation agencies, but there is excellent potential for power supply to the necessary charging infrastructure located at the highways with renewable energy supply for either solar farms or array of solar mounted at physical gores and separation areas between the highways. A practical application with the layout of the equipment was presented in the paper to allow planning of the wireless charging infrastructure at the roadways.

Keywords: Electric Vehicle Chargers, Renewable Energy, Smart Charging

INTRODUCTION

The charging of the batteries for smartphones wirelessly occurs because of the ability to transfer via a magnetic field between the two devices. The wireless charging is often classified as non-radiative and radiative charging, and acoustic power transfer [1]. However, plugin type charging is capable with slow and fast charging at varying capacities in kW [2] and charger connectors suitable for a given make model of car [3].Some researchers have documented the design for wireless charging of e-scooters at 200W and found experimentally effective [4]. The batteries supposedlyharness more power output from the hardwired connection rather than the wireless charging. The challenges with wireless charging include compatibility issues with the type of phone and charging equipment. Additional challenges include slow charging, environmental impacts, and undue heating of the devices. The principle that applies to the wireless charging system is electromagnetic resonance wherein oscillating electromagnetic field from one coil resonates with other coil and receives the electrical power using an electromagnetic field between the coils.

Figure 1 shows a diagram for wireless charging while in stationary mode. The charging while in-motion applies similar principles but the motion of the vehicles becomes a key difference when design of the system is considered. The scenarios for wireless charging while in-motion includes[5][6]: stationary when traffic is stopped, quasi-dynamic when vehicles either accelerate or decelerate, and dynamic when cruising at low, medium or high speed. The components of wireless charging infrastructureat roadway comprises of a power from electrical grid, conversion from AC to DC, high frequency convertor, and coils. Similarly at the vehicle it has receiving coils and other electronic components to charge the electric battery.

The EV batteries charge at a faster speed with ultra-fast chargers that may be readily available at commercial EV charging stations and hubs. Although the availability of charging stations is questionable, given the EV transition is in the planning and large-scale deployment stage, wireless charging while in-motion is an excellent concept with great potential to reduce charging time. Currently, the best achievable charging times to 100% SOC are between 20 minutes to 1 hour via ultra-fast chargers. Although the charging time wirelessly is significantly elongated, drivers may save a significant amount of time for charging at regular charging stations if they are able to charge by a significant amount while driving.

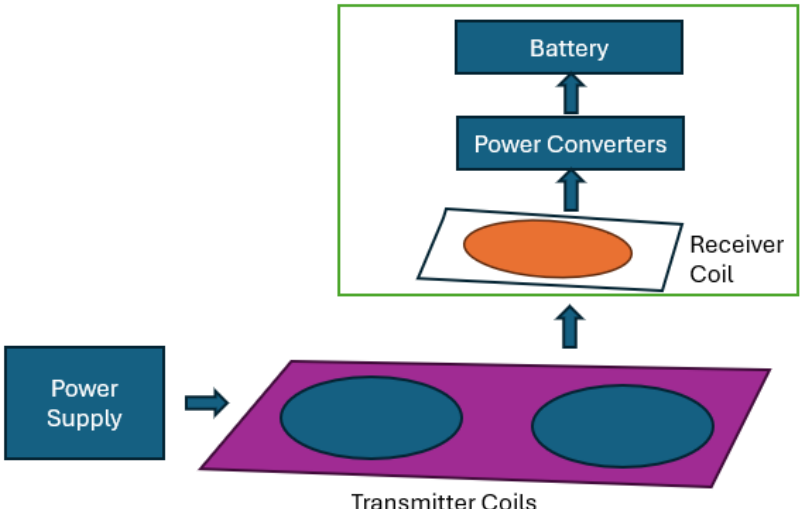

Figure 1 Wireless Charging [6]

There are several concepts in wireless charging while in-motion being developed at research labs in the United States aiming at achieving high efficiencies of charging without compromising the safety[7][8]. The energy transfer at higher intensity wirelessly poses issues when challenges with reducing operating voltage and current levels are considered from a design perspective. Especially when the roadways are exposed to heating from the charging technology, there could be damage to the system as they are exposed to external heat from sunlight and frictional forces from the vehicle motion and braking. The advantages from the wireless charging are not limited to reduction in charging time but also in minimizing the need of other kinds of charging infrastructure. For example, for traditional gasoline and diesel fueled vehicles drivers return to the fueling stations frequently[9]. However, with wireless charging at high efficiency and high output will limit the drivers visit to visit charging stations or hubs.

On the flip side, there is a great level of effort required by both car manufactures and transportation agencies to find a best fit of the technology with least disturbances to current transportation infrastructure. For example, major roadway resurfacing required from the wireless charging becomes a challenge especially the capital cost for such improvements are not short term plans. A long term planning and resource allocation for design development along with availability of funding is important. The environmental permitting for something on public space is concern as there are safety challenges with the heating and other operational issues with the wireless charging.

Detroit (Michigan) has deployed one of its kind wireless charging infrastructure that support cars while in-motion by the 14th Street[10][11]. The charging speeds were low and the speed of vehicle were required to be slow to achieve greater state of charge. The terminology of electrified roadway as coined by the Michigan Department of Transportation is a source of reliable charging to the customers without spending any additional effort. How the customer billed for the charge may be a subject of study but existing tolling system will serve as a starting point for billing the customers.

METHODS

Figure 2 shows how typical wireless charging equipment is laid out for a typical section of a highway with low pedestrian conflict.The roadway lanes deploy charging coils embedded in the concrete with a secured and protected layer of concrete and other non-metallic materials to strengthen the roadway surface and cause minimal damage from vehicle weight onto the embedded coils.

The reporting of the energy consumed, and billing may either be by use of tolling cameras or by providing an integrated dashboard tied via cellular network to report the change in state of charge of the battery while travelled on electrified roads. Figure 4 shows how a billing infrastructure be deployed either by tolling cameras or wirelessly by vehicles. The advantages of tolling camera is cost savings without adding new type of infrastructure. But is results in difficulty in enforcing exact chargers to the customers as with location information will not provide exact delivered power to the vehicle. To solve that problem the car themselves may record the consumption by tracking the state of charge (SOC) before entering and exiting the roadways and communicate it wirelessly.

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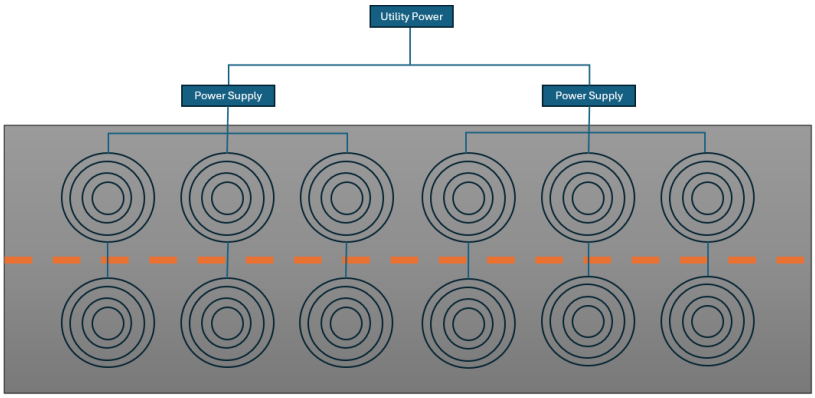

Figure 2 Concept of Wireless Charging

When studying the concept shown in Figure 2, it becomes clear that there is a required frequency of power supply to be located off the guard rails to protect the equipment from any crashes. Additionally, providing utility power to each of these power supply equipment requires planning. The potential presence of transmission and distribution lines along the roadways makes the practicality of powering wireless charging equipment possible. Authors have presented how a solar photovoltaic can be integrated for electric vehicle charging [12]. Figure 3 presents an innovative concept of adding a solar photovoltaic system at the unoccupied spaces the fall near the highways. There is absolutely no place where solar photovoltaic has zero potential so this concept is very useful. Additionally, solar power street lights and other equipment along the roadway are in practice where the utility power supply to that location is limited due to the cost of availability of the power distribution lines.

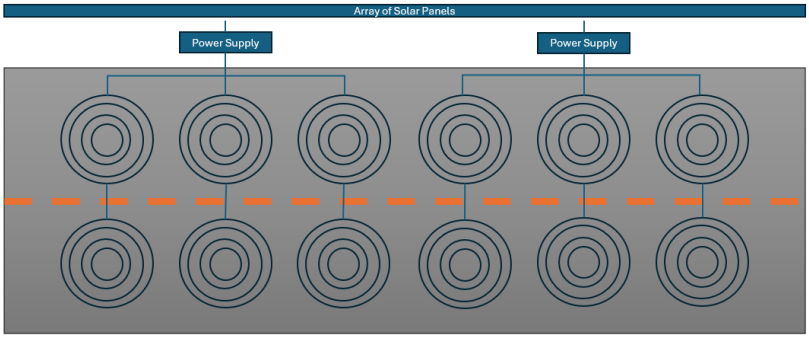

Figure 3 Concept of Solar PV for Wireless Charging

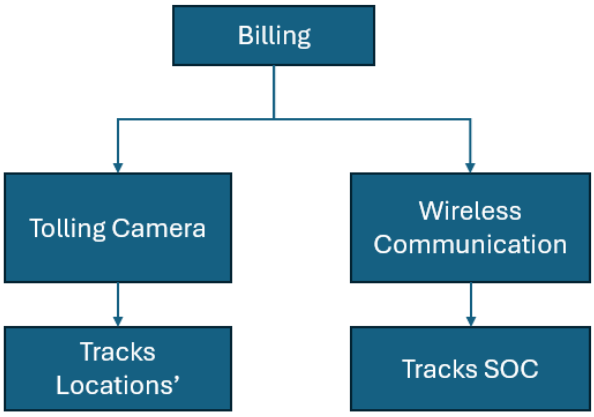

Figure 4 Billing Infrastructure

PRACTICAL APPLICATION AND RESULTS

A practical application is seen in Figure 5 where a set of solar photovoltaic systems power the power supply to the coils that are embedded inside the concrete of the roadway surface. As it is visible there is plenty of space to accommodate the equipment at this location.The size of the solar photovoltaic system is dependent on the available solar irradiance at the given location, and shading effects from nearby vegetation. Additional considerations are around the appropriate size of power supply to feed a fixed quantity of coils at given intervals along the highway. To ensure a more resilient system both solar and grid power can be integrated together to the system. The effective green house gases emissions reduction from this effort are subject to life cycle assessment of the whole system.

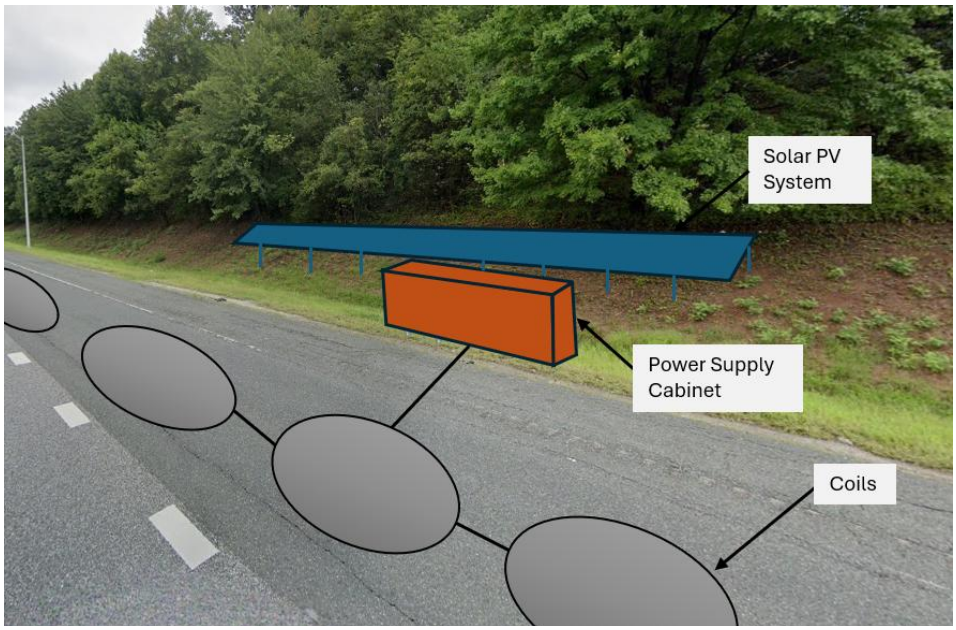

Figure 5. Layout of Equipment (Source of Background: Google Maps)

CONCLUSION AND DISCUSSION

A practical application where in EVs equipped with wireless charging features utilize charging not only while parked but also while in-motion on roadways was documented based on pilot projects and known technology. A concept was developed for a typical roadway section with use of solar photovoltaic system mounted at physical gore sections and separation spaces between the roadways. This concept of wireless charging while in-motion increases the customer satisfaction as there is no valuable time lost for charging. The concept of either availing power from the utilities or solar photovoltaic systems is a choice but there are added advantages from solar photovoltaic systems where there is lack of readily available utility power and where cost of utility power is greater than solar. Many environmentalists will favor solar to mitigate the climate change and thus solar power becomes a feasible solution. Additionally, the concept of recording the vehicle travel by tolling cameras is viable choice as it reduces the cost for additional infrastructure. However, the cars may be enabled with applications that communicate the state of charge of battery before entering and after exiting the roadway. The potential of renewable energy is not limited to just solar, as presented in the paper, but also extends to other renewable energy sources. The concept of carbon credits earned from this concept must be reported to the customers to increase awareness on use of renewable energy. There is a good chance that the customers will be encouraged to invest or utilize renewable energy as much as they can to reduce their carbon footprint.

Acknowledgment
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